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## REVIEW ARTICLE

# Radiation Safety in the Neonatal Intensive Care Unit: Too Little or Too Much Concern?

Cheng-Chung Yu

*Department of Pediatrics, The Mennonite Christian Hospital, Hualien, Taiwan*

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With rising numbers of extremely premature infants in the neonatal intensive care unit (NICU) who require multiple radiologic examinations for their complex medical conditions, concerns the risk of radiation exposure become a more prevalent issue. The biological effects from cumulative doses of both primary and secondary radiation can be particularly troubling for very premature babies due to their inherent sensitivity to both iatrogenic and environmental insults. Similarly, radiologic studies performed in the NICU pose potentially significant exposure risks to caretakers and to the families of patients often present in the NICU during these examinations. The purpose of this article is to critically review the available literature regarding current exposure rates in the NICU, address the validity of radiation exposure concerns, and suggest areas for improvement. With few exceptions, studies reveal that there were only low doses of radiation derived from any single radiographic examination in standard NICUs and that the radiation dosage used was in compliance with recommendations made by the Commission of European Communities (EC) and International Commission on Radiological Protection (ICRP). However, there were wide variations in the radiation dose per single examination (mean entrance skin doses ranged from 15 to 73.6  $\mu$ Gy) and in the frequency (mean ranged from 3.2 to 31 examinations per infant) of those examinations. Studies also reported low secondary exposure rates from scatter radiation to others present in the NICU during radiographic examinations. Key to limiting unnecessary radiation exposure in the NICU is the employment of proper radiation techniques and safety measures. Thus, adhering to recommendations made by the EC and ICRP can help to reduce the anxiety of patients' families and medical staff regarding their risks from the effects of ionizing radiation in the NICU.

## 1. Introduction

In western countries, premature delivery has been steadily increasing for the past decade. In the United States, delivery of late preterm infants (34 0/7 to 36 6/7 weeks gestation) has increased by 14% between 1992 and 2002.<sup>1</sup> The percentage of preterm infants below 36 6/7 week gestation is now around 12.5% of all deliveries in the US.<sup>1</sup> The majority of infants requiring admission to the Neonatal Intensive

Care Unit (NICU) face many potential iatrogenic problems. The most commonly cited iatrogenic issues in the NICU are nosocomial infection, anemia from frequent blood tests, and exposure to ionizing radiation. Potential nosocomial infections, especially catheter-related infection, MRSA (methicillin resistant *Staphylococcus*) colonization, and bacteremia are topics which receive a great deal of attention within the neonatal care community. Recently, rising awareness regarding anemia caused

Corresponding author. Department of Pediatrics, The Mennonite Christian Hospital, 44 Min-Chuan Road, Hualien, Taiwan.  
E-mail: [lukeyu@cox.net](mailto:lukeyu@cox.net)

by excessive blood testing has effectively limited blood draws to only those deemed truly necessary. However, the same degree of vigilance about exposure to ionizing radiation has not been reached within the neonatal care.

On one hand, caretakers in some NICUs seem philosophically unconcerned about the radiation exposure to a newborn from a single radiographic examination. However, less commonly do the tenuous conditions of these still developing neonates require a single study and, by the end of most extended stays in the NICU, the doses of ionizing radiation to these patients accumulate quickly. On the other hand, caretakers in other NICUs appear to be overly concerned about their own exposure from a single radiographic examination of their patient and may temporarily leave these most fragile of patients unattended in an effort to avoid the effects of ionizing radiation.

The purpose for this article is to provide a quick overview of the fundamentals of radiation exposure, review the available literature regarding current radiation exposure rates in the NICU, and to provide an understanding of the potential hazards of ionizing radiation to patients, families, and caretakers in the NICU. It is the hope of the author that this article will provide a helpful foundation for instituting realistic goals for the use of radiographic examinations in common neonatal practices.

## 2. Fundamentals of Radiation

There are two primary sources of radiation, natural background and man-made radiation, the contribution of the former being far greater than the latter.

### 2.1. Background radiation

*Natural background radiation* is derived from two significant sources, terrestrial and cosmic.

*Terrestrial radiation* emanates from our natural surroundings, such as soil and water. It arises in low intensity from common elements, such as from the decay of  $^{40}\text{K}$  and  $^{14}\text{C}$  incorporated inside the human body, or in high intensity from rare elements, such as from the decay of uranium (Table 1<sup>2</sup>). Thus, depending upon the distribution of such sources in any one area, the contribution of terrestrial radiation varies with location.

*Cosmic radiation* accounts for the remainder of radiation from natural sources. Radiation originating from outside this solar system, in the form of energetic protons and alpha radiation, is absorbed in the upper atmosphere so that only a very small percentage (<0.05%) reaches sea level.

**Table 1** Typical annual background radiation exposure in the United States<sup>2</sup>

Radiation source	Exposure
Radon	2.0 mSv/yr
Cosmic rays	0.3 mSv/yr
External (gamma rays)	0.3 mSv/yr
Internal (e.g., $^{40}\text{K}$ , $^{14}\text{C}$ )	0.4 mSv/yr

### 2.2. Man-made radiation

In addition to natural background radiation, radiation is also created by man-made processes, which can be divided into nonmedical and medical sources.

*Nonmedical radiation* is derived from a variety of consumer products, including building materials, luminous watches, smoke detectors, and airport X-ray inspection systems. The entirety of the nuclear fuel cycle, from mining to disposal of nuclear fuels, as well as fallout from atmospheric weapon testing in the 1950s has also contributed to overall public radiation exposure.

Radiation used for medical purposes, which stems from the approximately 300 million diagnostic medical procedures performed a year in the US, includes both radiographic and nuclear medicine examinations. Diagnostic procedures using ionizing radiation, such as X-ray and computed tomography examinations, account for the majority of medical man-made radiation exposure.

Because radiation exposure in the NICUs is largely due to ionizing radiation generated from portable X-ray machines, this article will concentrate on only X-ray related radiation.

### 2.3. How is an X-ray image produced?

An *X-ray beam* is created when a beam of electrons is released from the cathode of an X-ray tube and hits a tungsten metal anode. This X-ray beam is an electromagnetic wave, similar to visual light but with a shorter wavelength and greater intensity. To produce a diagnostic image, the beam is directed at the patient in a straight line at the speed of light through a window in the X-ray tube. Once the beam reaches the patient, it is absorbed by the different tissues of the body to variable degrees, depending on the thickness and density of the target tissues. The part of the X-ray beam that is not absorbed by the body hits a photosensitive cassette positioned behind the patient. When the X-ray beam encounters thicker portions of the body, these areas absorb a larger portion of the X-ray beam as compared to thinner regions. Very dense tissues, such as bone, absorb almost all of the energy of the X-ray beam;

conversely, less dense tissues, such as fat, absorb a relatively smaller amount of energy from the X-ray beam. The varying degrees of X-ray absorption by the patient's tissues account for the differing densities of shadows that become a recognizable composite of the patient's body on the X-ray image.

## 2.4. How is radiation dose measured?

Radiation exposure refers to the amount of ionization in the air which is caused by the level of radiation intensity. When radiation interacts with tissues of the body, the transfer of energy from radiation to these tissues is called the radiation dose. The dose of radiation to a patient exposed to an X-ray beam is affected by three variables: the amount of energy in the X-ray beam (milliamperes, mA), the duration that the X-ray beam is applied (seconds, s), and the area over which the X-ray beam is applied (squared centimeters, cm<sup>2</sup>).

The *entrance skin dose* is the simplest method by which to quantify radiation dose as it measures the radiation incident upon a patient's skin surface during a radiologic examination. While easy to calculate, this measurement is a poor indicator of the actual patient risk from radiation exposure because it does not take into account the area of exposure, strength of the X-ray beam, or the radiosensitivity of the target tissues.

The *dose-area product* attempts to more accurately measure radiation dose by taking into account the area exposed to radiation. It is defined as the product of the entrance skin dose and the cross-sectional area exposed to the X-ray beam. This product is a useful tool for providing relative patient risks when comparing similar types of radiographic examinations.

Similarly, the *absorbed dose* attempts to calculate radiation dose by measuring the amount of radiation energy deposited per unit mass of a given tissue. Absorbed dose is expressed in units of gray (Gy) or rad where one gray dose is equivalent to one joule radiation energy absorbed per kilogram of tissue weight (J/kg).

A final measurement called the *equivalent dose* takes into account the fact that different types of ionizing radiation produce different degrees of harm to exposed tissues; for example, alpha particles cause greater damage to living tissues than do X-rays, gamma rays, and beta particles. To this end, the equivalent dose is defined as the absorbed dose multiplied by a *radiation weighting factor* (*w*) and is expressed in units of Sievert (Sv) or rem.

Since the radiation weighted factor of X-rays is one, the absorbed dose and the equivalent dose are equal in diagnostic radiographic examinations. The importance of this measurement is that, unlike

the previously mentioned methods for measuring radiation dose, it reflects biological effects of radiation on the body. Thus, the equivalent dose can be used to predict a patient's or population's risk of developing cancer and is applied in the determination of radiation protection needs.

The biological effect of radiation refers to its effect on living cells. Radiation can damage sections of DNA, suppress the division of cells in metaphase during mitosis, and cause changes in the genetic code (called a mutation) during meiosis. The end results alter the function of cells, sometimes inducing cancerous changes or cell death. In diagnostic imaging, the biological effects of radiographic examinations depend on the radiosensitivity of the target tissues. Specifically, "the radiosensitivity of tissues depends upon the number of undifferentiated cells which the tissue contains, the degree of mitotic activity in the tissue, and the length of time that the cells of the tissue stay in active proliferation," according to the law of Bergioner and Tribondeau.<sup>3</sup> It follows that patients undergoing fast rates of development, such as embryos, fetuses, and newborns, are far more vulnerable to the effects of radiation than adults. Similarly, it is not surprising that hematopoietic system and gonads are the most radiosensitive portions of any body and the central nervous system, liver, and thyroid gland are relatively more radioresistant.

There is a great deal of uncertainty regarding the true estimation of cancer risk after radiation exposure. Risk from radiation exposure has been estimated by several scientific groups. It should be noted that the risk estimates for a population does not necessarily predict the risk for a specific person. Stewart and Kneale<sup>4</sup> estimated that the risk of childhood cancer from *in utero* exposure that ended with actual death by an age of 10 years was 57 in 1000 cases with a standard error of 13 in 1970. That number was not accepted by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 1972 and 1977. The authors of UNSCEAR suggested that the risk was about 23 in 1,000 cases with a standard error of 5–6. It should also be noted that the numbers were calculated from the cases of actual deaths at the age of 10 years. Therefore, the actual risk from an obstetric radiograph is higher if those patients who did not expire by the age of 10 were included. Fletcher et al<sup>5</sup> adjusted the risk by multiplying by a factor of 1.5 to allow for those patients who did not die by the age of 10. The final risk by unit dose was 53 cases per 1000Gy of entrance skin dose. They also calculated the risk of cancer in their study for chest with abdomen (babygram) and CT scan were 1 in 280,000 and 1 in 300 respectively using 0.07mGy of ESD for babygram and 62mGy of ESD for CT scan. These numbers of estimated risk appears to be overestimated.

Later according to the International Commission of Radiological Protection (ICRP) report 60,<sup>6</sup> the risk of childhood cancer by dose unit due to prenatal exposure varies from  $2.8 \times 10^{-2}/\text{Sv}$  to  $13 \times 10^{-2}/\text{Sv}$ . Many authors have used these measurements of childhood cancer risk to estimate the radiation effect for all infants prior to 37 weeks' gestational age. Using these numbers, the calculated risk of developing cancer from a single neonatal radiography was reported to be in the order of  $(0.3-1.3) \times 10^{-6}$  by Armpilia et al<sup>7</sup> and  $(0.4-2) \times 10^{-6}$  and  $(0.6-2.9) \times 10^{-6}$  for single chest and abdomen radiographs, respectively, by Olgar et al.<sup>8</sup>

### 2.5. Annual radiation dose limits recommended by ICRP

ICRP is an advisory body established to provide recommendations and guidance regarding protection against ionizing radiation. In particular, recommendations by the ICRP for the general public is 1 mSv per year with an average annual dose of 20 mSv over 5 years and a maximum dose of 50 mSv in a single year. For a child-bearing woman, the recommended dose limit is 1 mSv during the 9 months of pregnancy (Table 2<sup>9</sup>).

Recommended dose limits for workers with occupational exposure to radiation are higher than that for the general public. Thus, the dose limit for the fetus of a radiation worker is 5 mSv, five times greater than that advised for the general public. The rationale for this higher dose limit is to avoid depriving a job opportunity for a pregnant worker in radiology. However, it should be noted that the radiation dose for the fetus of a radiation worker should never exceed a dose of 0.5 mSv per month of radiation exposure.

When radiographic examinations are performed with the assistance of medical staff, the assistant to the radiographer should wear a lead apron and radiometer to document their exposure during the examination. Pregnant caretakers in the room should also wear a dosimeter on their abdomen to document exposure to the fetus throughout the pregnancy.

**Table 2** Recommended dose limits for radiation workers by International Commission on Radiological Protection in 1991<sup>9</sup>

Parameter	Dose limit
Whole body	20 mSv/yr (2 rem/yr)
Lens of the eye	150 mSv/yr (15 rem/yr)
Extremities (hands)	500 mSv/yr (50 rem/yr)
Lifetime whole body	<800 mSv (<80 rem)
Fetus (9 mo)	1 mSv (100 mrem)

### 3. Clinical Implications in the NICU

In recent years, a growing number of premature and sick newborn infants have survived due to the prenatal use of steroid and postnatal administration of surfactant. These infants are some of the most vulnerable to radiation but also require the most frequent diagnostic radiological examinations during their stays in NICU. This was well illustrated in data from a large series of newborns ( $n=2408$ ) who were admitted to a NICU in Japan; Ono et al<sup>10</sup> in 2002 analyzed the relationship between the frequency of radiographic examinations to birth weight and gestational age. They reported that lower birth weights, gestational ages, and longer stays in the NICU were associated with a greater number of total X-rays. In this series, the average number of X-rays performed on infants weighing less than 750 g at birth was 26 as compared to 2.6 on infants with birth weights more than 2500 grams. One other study in France<sup>11</sup> in 2006 reported similar findings in Paris. They also compared total cumulative doses between two studies. The cumulative doses of radiation including CT scans on very low birth weight infants were 720  $\mu\text{Sv}$  in Japan and 497  $\mu\text{Sv}$  in France. Although CT examinations were not discussed in this article, it is worth mentioning that the use of CT for imaging newborn patients dramatically increases the radiation exposure to these patients by 10-fold compared to X-ray examinations and should be carefully reserved for specific clinical scenarios.

An earlier study by Wilson-Costello et al<sup>12</sup> in 1996 included data regarding frequency of radiographs in the NICU as well as radiation doses. In this study, the mean frequency of radiographs was 31 per patient; for the most ill infants with necrotizing enterocolitis or chronic lung disease, the average frequency of radiographs reached as many as 35 per patient. The estimated skin entrance dose and calculated equivalent doses for all 25 surviving infants with birth weight less than 750 g were reported. The total body equivalent doses per single exposure ranged from 0.01 to 0.02 mSv for a chest radiograph, from 0.02 to 0.04 mSv for a babygram (a combined image of the chest and the abdomen), and from 0.01 to 0.03 mSv for an abdominal radiograph. The radiation doses for each type of radiograph is important to note because, unlike the Japanese study in 2002 where the majority were babygrams followed by chest X-rays and abdominal X-rays, the most common type of radiographs in this earlier study were chest X-rays followed by abdominal X-rays and babygrams. This may reflect a current trend toward more frequent imaging with examinations which impart greater radiation doses to patients per exposure.



It should be noted that, in reviewing the literature regarding frequency rates of radiographs performed in the NICU, there are large variations (mean: ranged from 3.2 to 31 examinations per infant)<sup>7,10</sup> in the number of examinations reported between studies, among different institutions, and among individual patients within a single NICU. These differences between studies and within single studies may reflect inherent differences between sampled patient populations (for example, severity of illness at a tertiary center versus general population in a community hospital) or simply different standards of practice.<sup>13</sup> If the latter is the case, it supports the argument that a more standardized protocol for imaging patients in the NICU may be indicated to reduce unnecessary radiation exposure across the board.

### 3.1. Primary radiation to infants in the NICU

The recommended radiation exposure limit by the Commission of EC is 80  $\mu$ Gy and by the National Radiological Protection Board is 50  $\mu$ Gy for chest radiographs.<sup>7</sup>

Despite concerns raised regarding overexposure during radiographic examinations in the NICU, all

studies in the reviewed literature demonstrated that exposure levels in nearly all single radiographic examinations were low in modern NICU. However, it is still important to strictly practice the ALARA (“as low as reasonably achievable”) principle because patients in the NICU remain particularly vulnerable to the cumulative effects of radiation exposure over their lifetimes. Uncertainty regarding the dose-effect relationship between ionizing radiation and biological damage, particularly in very low birth weight infants, should also drive this practice.

Since Smith et al<sup>14</sup> in 1979 reported a data series addressing radiation exposure rates in the newborn nursery, there have been several more studies measuring the entrance skin doses and effective doses in the NICU. A few representative reports are summarized in Table 3.<sup>6–8,14–21</sup>

The breadth of these studies demonstrates wide variations in terms of the radiation dose per single radiographic examination. Also, there are significant variations in the type of examinations most commonly performed; there are even variations when comparing NICUs at different hospitals analyzed in a single data series. These dissimilarities may be due to differences in the methods used to estimate,

**Table 3** Summary of entrance skin doses (ESD), effective doses (ED) and risk factors for childhood cancer in the literature<sup>6–8,14–21</sup>

Reference	Examination	kVp/mAs	ESD ( $\mu$ Gy) per radiograph	ED ( $\mu$ Sv) per radiograph	Risk ( $\times 10^{-6}$ ) (ED $\times 13 \times 10^{-2}$ )
Olgar et al (2008) <sup>8</sup>	Chest	49/1.9	67	15	2
	Abdomen	48/2.0	65	22	2.9
Brindhaban & Al-Khalifah (2004) <sup>15</sup>	Chest	57/1.6	60	26	—
	Abdomen	57/1.6	60	32	—
Jones et al (2001) <sup>16</sup>	Chest	62/2.0	56.7	15.4	2
	Abdomen	62/2.5	73.6	21.9	2.8
Armpilia et al (2002) <sup>7</sup>	Chest	53/2.0	36	7.8	1
	Abdomen	53/2.0	39	10.2	1.3
McParland et al (1996) <sup>17</sup>	AP chest	52–60/0.8	20	—	—
	AP abdomen	52–60/0.8	20	—	—
	AP chest & abdomen	62–70/0.4–0.5	15	—	—
	AP abdomen	—	—	—	—
Smith et al (1979) <sup>14</sup>	Chest	60–70/1.0	44	—	—
	Abdomen	60/1.0	49	—	—
Robinson & Dellagrammaticas (1983) <sup>18</sup>	Chest	60/1.0	53	—	—
	Abdomen	60/1.0	57	—	—
Fletcher et al (1986) <sup>6</sup>	Chest & abdomen	50/0.4	70	—	—
Faulkner et al (1989) <sup>19</sup>	Chest & abdomen	52/2.0	58	—	—
	Chest & abdomen	46/2.0	39	—	—
Chapple et al (1994) <sup>20</sup>	Chest	—	55	—	—
Wraith et al (1995) <sup>21</sup>	AP chest	60/1.0–2.0	36	—	—
	AP abdomen	—	38	—	—

measure, or calculate radiation exposure. However, the most relevant and perhaps correctable sources of these differences may lie in the types of equipment as well as the techniques used to obtain these radiographic examinations.

Technical considerations when calculating the entrance skin dose include the intensity of the X-ray beam (kVp), product of current-time of exposure (mAs), focus-to-skin distance, and the area of exposure. A study by Armpilia et al<sup>7</sup> and McParland et al<sup>17</sup> reported that using higher X-ray beam intensity and shorter time of exposure resulted in the same quality of radiographic examination at a much lower entrance skin dose. Duggan et al<sup>22</sup> estimated a decrease in radiation exposure by 9% if X-ray tube potential was increased from 50 to 60kVp. Based on this data, it follows that older portable X-ray machines that cannot achieve a higher X-ray beam intensity or that cannot allow for fine adjustment of the exposure time will result in higher radiation doses; thus, simply replacing equipment can reduce radiation doses in NICUs that still use older machines.

Proper collimation of the X-ray beam is one of the most important methods by which to limit radiation exposure in the NICU. The EC and World Health Organization (WHO) recommend proper image sizing for both chest and abdominal X-rays. An ideal chest examination should include the lower cervical area at the superior margin of the image and the upper edge of the abdomen at the inferior margin of the image. The skull and upper extremities should not be included in the examination. An ideal abdominal examination should include the diaphragm at the superior margin of the image and the symphysis pubis at the inferior margin of the image with gonads excluded and shielded if possible. The guidelines for field size are made to limit the radiation exposure to only the organ or tissue of interest; in this way, the amount of radiation can be reduced by decreasing the dose-area product (product of the entrance skin dose and cross-sectional area of the X-ray beam).

A few studies have shown that improper collimation of the X-ray beam is certainly a valid concern in modern NICU settings. Soboleski et al<sup>23</sup> in 2006 analyzed chest radiographs and found that only 55% of each images actually consisted of the lung fields and that 45% consisted of unnecessarily imaged organs or tissues. Additionally, the ratio of lung parenchyma to film size was particularly low for smaller sized patients; findings such as this raise concern for the unnecessary irradiation of thyroid tissue which is a known risk for the development of thyroid cancer. In 2007, Bader et al<sup>24</sup> reported a similar concern for unintentional exposure during chest and abdominal examinations performed in

the NICU. They found that 85% and 45% of chest radiographs inadvertently included the whole abdomen and neck, respectively. They also reported 62% and 31% of abdominal radiographs included the thighs and male gonads. The author of this paper notes the technical difficulty of shielding female gonads but feel that the ALARA concept should always be followed.

Some within the neonatal community have cited the very small size of patients in the NICU as a limitation for proper collimation technique. However, in 2008, Datz et al<sup>13</sup> found that proper collimation with reduction of at least 50% of unnecessary radiation exposure was feasible regardless of gestational age, birth weight, or patient size; instead, inexperience or unsatisfactory technique on the part of the X-ray machine operator were the primary culprits for poorly sized images. These investigators concluded that improvements in neonatal radiographic techniques were both needed and possible. Thus, while there are clearly clinical indications for obtaining babygrams in the NICU (such as for the visualization of umbilical catheters spanning both body compartments), these examinations should not be routinely taken if the target organ is located solely within the chest or abdomen.

While providing too large a radiograph size is a concern at one end of the spectrum, care must also be taken to avoid overcollimation of the X-ray beam since too narrow an imaging window can be counterproductive if one or more repeat examinations then become necessary; repeat examinations only increase the overall radiation exposure to the patient. Because it is difficult to obtain the perfect balance between the radiation exposure needed to provide a diagnostic quality image and to protect the patient from the detrimental effects of ionizing radiation, it would be ideal to limit imaging of neonatal patients to only properly trained radiographic technologists who have full knowledge of the considerations involved in the precise imaging of these vulnerable patients.

### 3.2. Environmental concerns in the NICU

Thus far, this article has dealt with the effects and clinical implications of ionizing radiation on patients being imaged in the NICU. However, there are also radiation safety considerations for family members, other patients, and medical staff who remain within the vicinity of a radiographic examination performed within the NICU. To understand the potential effects of radiation exposure to others in the NICU, it is important to first review the concepts of scatter radiation and the inverse square law.

When an X-ray beam exits the X-ray tube, the portion of the beam that travels through the air and is

incident upon the patient is called primary radiation. Most of this radiation is absorbed by the air and the patient, but some X-ray energy is reflected off of the patient in many directions and is called scatter radiation, or secondary radiation. It is this radiation source that poses potential exposure risks to those in the areas surrounding a patient in the NICU.

When scatter radiation emanates from the patient during a radiographic examination, it possesses far less strength than the primary X-ray beam. This is partly due to the fact that the patient from whom the scatter radiation originates from absorbs a part of the original X-ray beam energy and partly due to the inverse square law. The *inverse square law* states that the intensity of any given X-ray diminishes very quickly with distance from the source of the X-ray; specifically, there is a nonlinear fall-off in radiation intensity which is proportional to the square of the distance from the radiation source. When the distance from an X-ray source doubles, there is a four-fold decrease in X-ray beam.

A few studies have addressed the issue of environmental radiation exposure in NICU and have demonstrated very low amounts of secondary radiation in the NICU. Poznanski et al<sup>25</sup> in 1974 measured radiation inside a NICU; the authors found that radiation exposure was 70  $\mu$ R within a one-foot radius (approximately 18 mrad/year). Assuming a background radiation of 100–150 mrad/year, they concluded that this exposure level was sufficiently low enough to obviate the need for personnel to leave the room when radiographic examinations were performed. A later study in 1995 by Iyer et al<sup>26</sup> used thermoluminescent dosimeters in various locations in the NICU to measure scatter radiation. They found negligible radiation exposure levels and also concluded that there was no need to move neighboring patients or personnel away from the patient receiving a radiographic. In 1999, measurements of scatter radiation in a study by Duetting et al<sup>27</sup> demonstrated that measured scatter radiation in the NICU were significantly lower than the dose permitted to the public by ICRP guidelines, again underscoring that low risk of radiation exposure to neighboring infants, their families, and caretakers.

An interesting study in 2003 by Burrage et al<sup>28</sup> measured scatter doses of radiation per single radiographic examination during different radiographic studies using a “newborn” anthropomorphic phantom. At one meter distance from the radiation source, the authors reported incident scatter radiation levels of 0.024  $\mu$ Gy, 0.027  $\mu$ Gy, and 0.041  $\mu$ Gy for chest radiographs, babygrams, and skull radiographs, respectively. They concluded that, when allowing for up to three examinations per day, the annual absorbed dose from scatter radiation (0.05 mGy) is sufficiently low enough to warrant not

shifting adjacent patients if they remain one meter from the radiation isocenter. For technologists and medical staff who are also one meter from the radiation isocenter, the annual dose was estimated to be 0.04 mSv which is also less than the recommended dose limit for radiation workers (20 mSv), pregnant workers (1.0 mSv), and the general public (1.0 mSv) set by the ICRP.

Overall, these low reported exposure rates due to secondary radiation in the NICU should help alleviate anxiety regarding risks to other patients, family members, and caretakers.

## 4. Conclusions and Recommendations

A few salient conclusions may be drawn from the available literature discussing radiation exposure in the NICU.

- (1) The exposure rates from primary radiation from a single radiographic examination is low and below the recommended dose limits by the EC and by the National Radiological Protection Board.
- (2) Frequency of radiographic examinations per NICU patient appears acceptable. However, the rise in number of extremely low birth weight infants surviving in the NICU raises new concerns for this subset of patients who may be particularly at risk to the effects of ionizing radiation given their inherent vulnerability to environmental insults.
- (3) There are well documented variations in exposure rates for the same patient between different types of radiographic examinations and between different patients undergoing the same radiographic examination. There are also large variations between different hospitals in terms of the number of radiographic examinations performed in their NICUs. These differences raise concerns for consistent radiographic techniques, such as proper collimation, used to obtain studies and highlight the need for standard imaging protocols among NICUs.
- (4) If a fair distance (at least one to two meters) is maintained, secondary radiation exposure for persons in the vicinity of a radiographic examination performed in the NICU is also low and does not warrant unnecessary anxiety on the part of family members or caretakers. Specifically, there is no need for caretakers to interrupt their care of the patient or neighboring infants nor to leave the room while a radiographic examination is performed.

There remains a great deal of uncertainty regarding the long term effects of ionizing radiation on patients in the NICU. With this in mind, several

suggestions for best limiting radiation exposure in the NICU can be made:

- (1) To more consistently limit overall radiation exposure in the NICU, nonradiation image modalities, such as ultrasound, should be considered and a protocol for ordering radiographic examinations in the NICU for defined diagnostic questions could serve as a standard by which to guide neonatal practitioners. This may be most helpful for those still in training or just beginning practices in the community. Such guidelines would serve to distinguish those clinical situations in which radiographic examination affects subsequent management decisions from those which do not. Additionally, the relevant radiographic examination tailored for a given clinical question could be specified in these guidelines to prevent exposures to parts of the body not in question. In this way, overly frequent examinations could be reduced.
- (2) Technical protocols for the performance of radiographic examinations in the NICU could also be well-defined for each hospital. The goals of these protocols should encompass the equipment as well as techniques used for making fine adjustments in X-ray beam intensity and collimation so that the lowest radiation doses possible are utilized to create the highest diagnostic quality X-ray images. ALARA principle should always be followed when a radiographic examination is performed. Some guidelines are already set by organizations such as the EC and WHO for precise collimation techniques and protective shielding methods so that only target areas are exposed to radiation and can be adopted in modern NICU practices. Because studies have shown that many correctable sources of radiation overexposure are operator dependent, these protocols can be useful in properly training technologists who perform examinations in the NICU.
- (3) It is legitimate for NICU staff to be concerned about their personal radiation risks given the daily use of radiographic examinations in their work environment. However, knowledge of true radiation exposure levels at their institution and of reasonable preventative radiation safety measures are important to keep their exposure rates below dose limits for radiation workers. Simple measures such as maintaining a fair distance (at least 1–2 meters) between the radiation isocenter take advantage of basic concepts such as the inverse square law to rationally limit exposure. If fair distances are maintained and other radiation safety measures are followed, behaviors such as abandoning caretaker duties to infants and parents in the NICU in order to

maintain large distances from the radiation isocenter will not further protect the caretaker any more significantly and certainly creates additional dangers for patients and an environment of anxiety for the parents in the NICU.

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